

# Collaborative Demonstration for GNSS-augmented Tsunami Early Warnings

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# Our Goal



## Leverage NASA research investments in

- Real-time GNSS (global navigation satellite system)
- Earthquake early warning
- Tsunami early warning to augment the speed and accuracy of the NOAA National and Pacific Tsunami Warning Centers (NTWC and PTWC) response process.

## Advance readiness toward application

- Demonstration of integrated and collaborative science and technology
- Evaluation and Testing with end users
- Transition of research results to operational applications (*R2A*)

NASA Earth Science  
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# Give credit to...

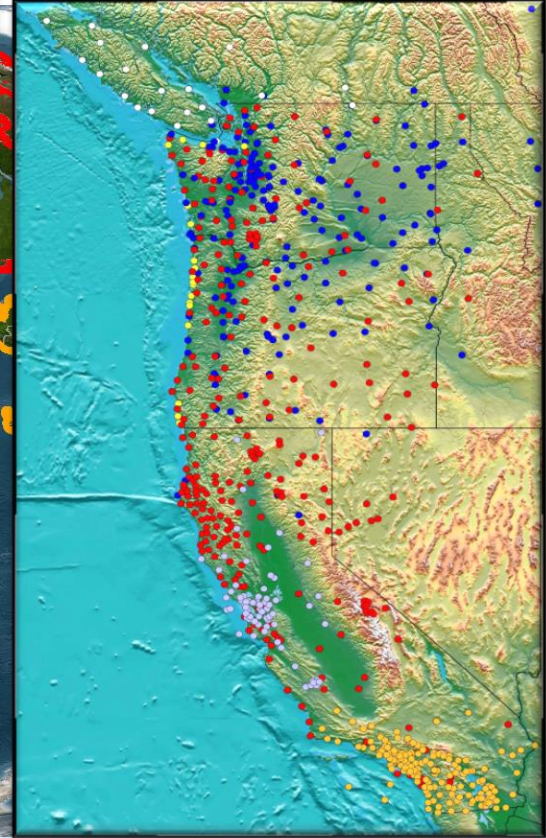
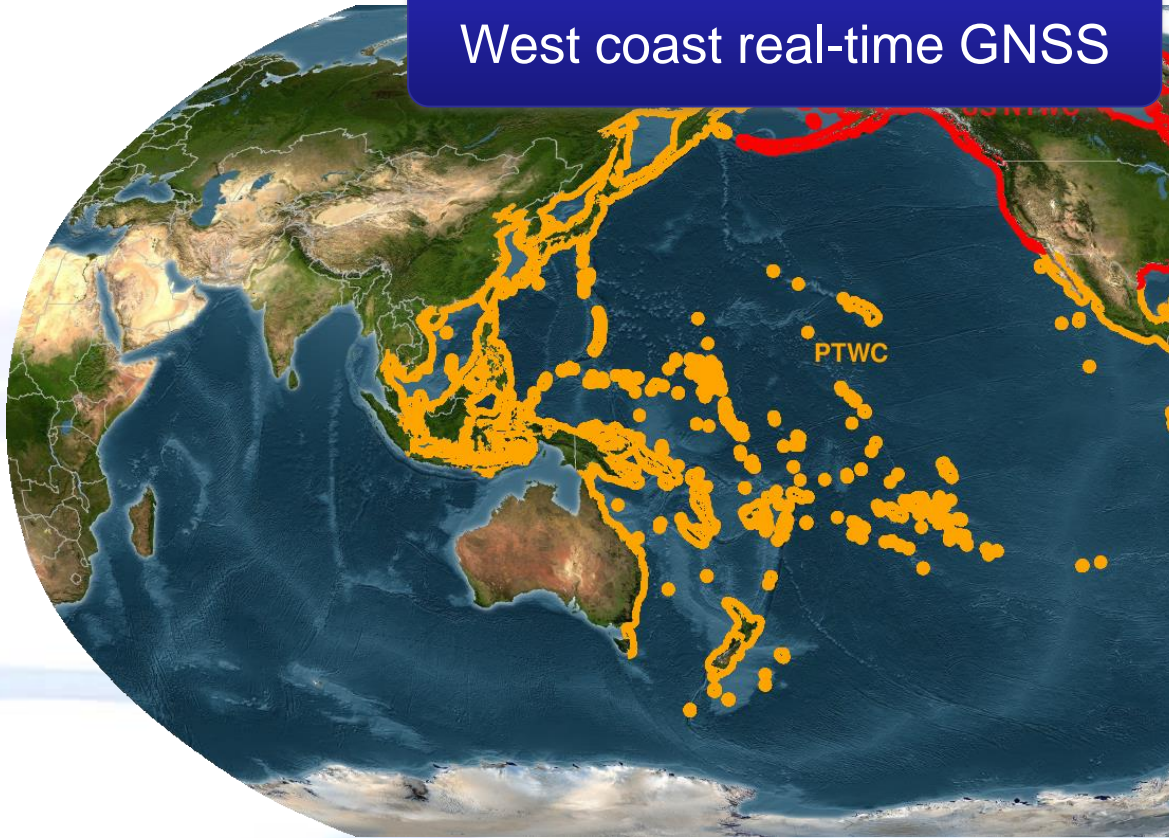


- NASA Earth Science
  - Research and Analysis, Technology, and Missions
- NOAA National Weather Service
  - Operational Tsunami Early Warning Centers
- NASA Applied Science - *is what we're all about!*
  - Transition of NASA Earth Science & Technology to end users
- ROSES RRNES
  - Cooperative agreement for Rapid Response and Novel Research in Earth Science

# NOAA Tsunami Warning Centers

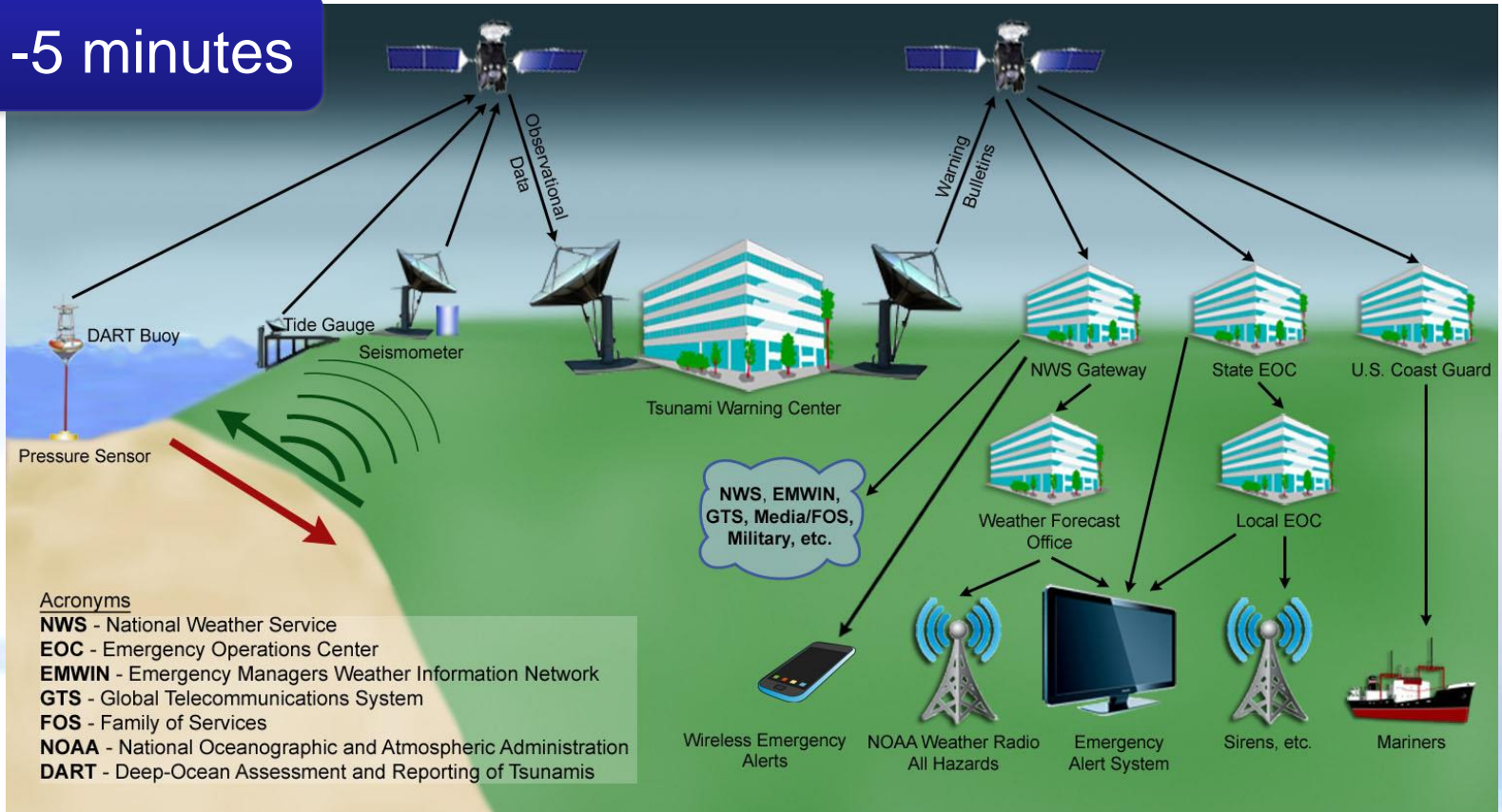


West coast real-time GNSS



# How Tsunami Warning Works

...in 1-5 minutes



# NASA Funded Contributors



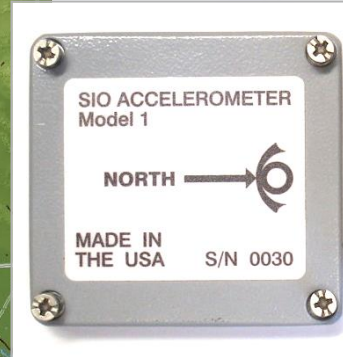
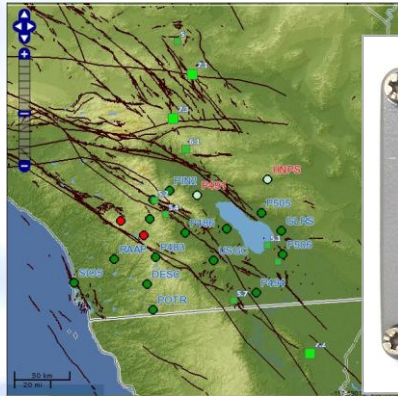
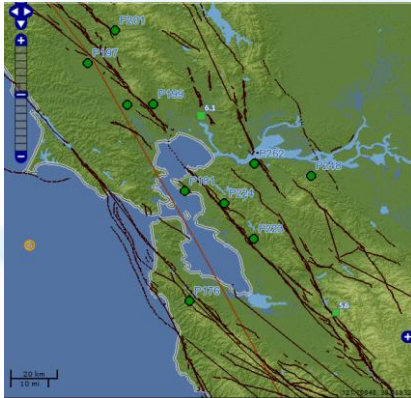
- **Scripps Institution of Oceanography**
  - Seismodeogetic Sensors
  - GNSS Processing
- **NASA Jet Propulsion Lab**
  - Global Differential GPS (GDGPS) Network/Processing
  - Tsunami Source Function Estimation
- **University of California Berkeley**
  - Historic Data
  - *Fakequake* Scenarios
- **University of Washington**
  - Geodetic Algorithms
- **Central Washington University**
  - GNSS Processing
  - Communication/Merging



# Scripps Institute of Oceanography



- Leads the Real-Time Earthquake Analysis for Disaster Mitigation (READI) Network
- Developed MEMS Seismogeodetic Sensors
  - Deployed in Bay Area by UNAVCO
  - Deployed in Southern California on SCIGN

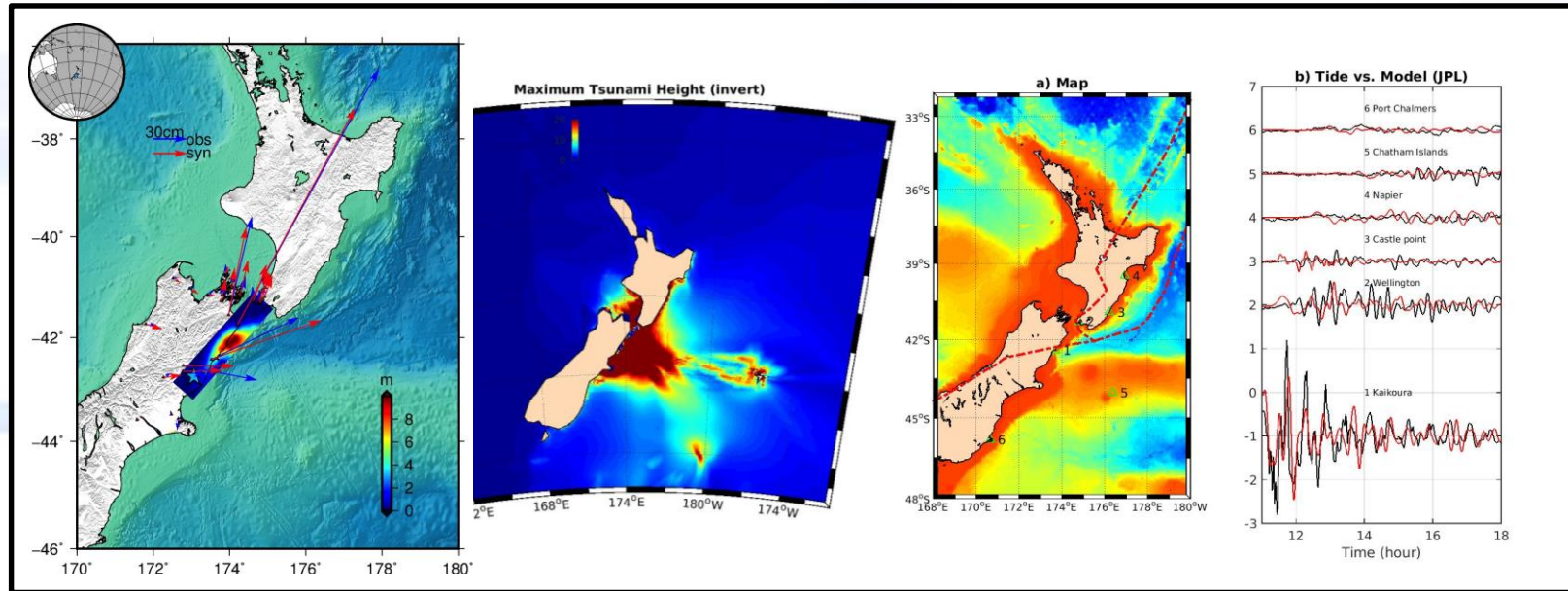




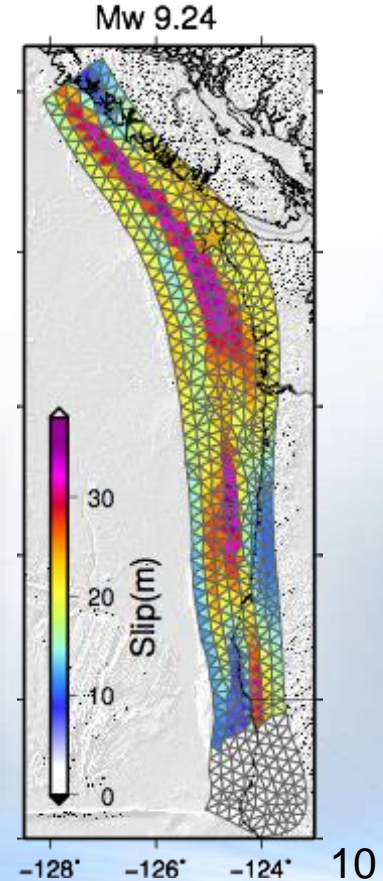
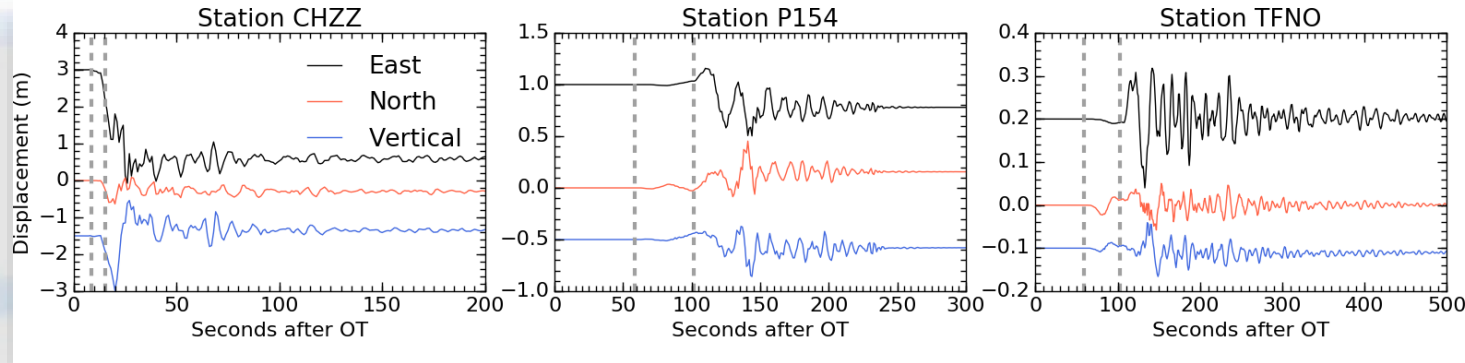
# Jet Propulsion Lab



- GPS-Aided and DART-Ensured Real-time (GADER) Tsunami Early Detection System
- Global Differential GPS (GDGPS)
  - 250+ Global and Regional GNSS Stations Currently Served

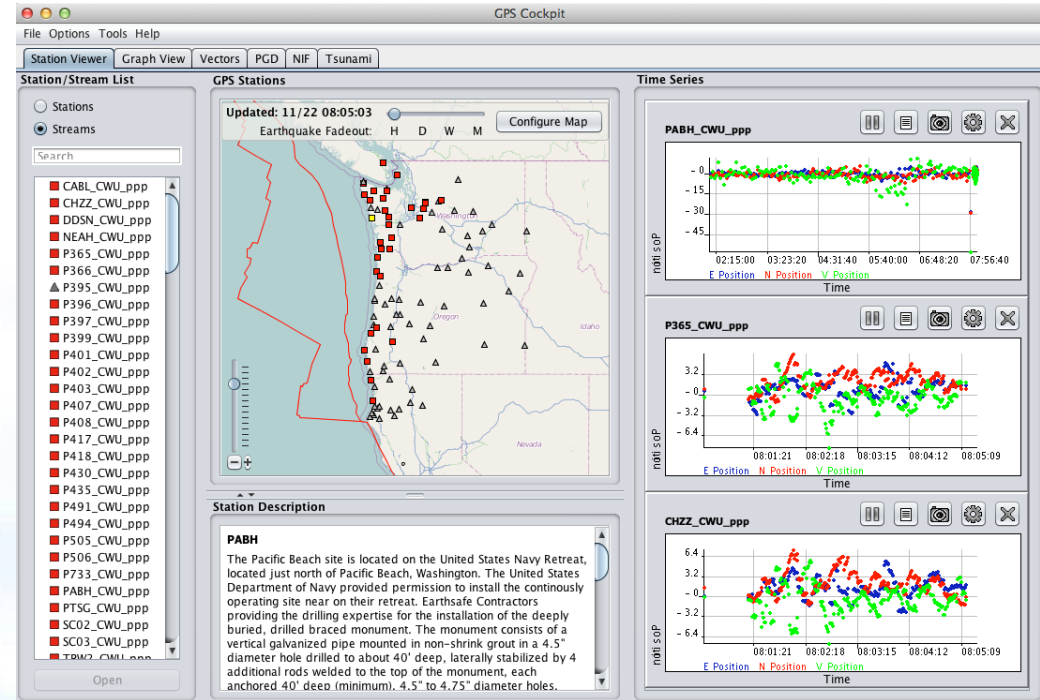


- Developed *Fakequakes* and Event playback tools
- Contributed to evaluation & testing and exercise participation



Contributed and Developed

- *RabbitMQ* casting
- Kalman filter based merging of solutions
- *GPS Cockpit* network monitoring
- Cascadia megathrust fault continuous estimation
- PANGA network





# A New Approach ! Research to Application (R2A)



- Team Building with Program Management
- Intensive and Tactical Webinar and Face-to-face Meeting Series
  - Gained shared understanding of mature research results, available technologies, data access and operational system opportunities
  - Enabled collaborative design
  - Committed to integrated plans and implementation objectives
- Rapid Response Funding – unique and timely
- On-going Commitment and Engagement

# NTWC Meeting, Palmer, Alaska



- Shared understanding of an Operational Tsunami Warning Center process
  - Quick Response Dominates
  - State of the Art is Hands-on
  - Where does GNSS Fit In?
- Develop an Architecture
  - Data and Functionality
  - Module Design
- Integration Plan
  - Testbed to evaluate capabilities and transition



# Tsunami Response Timeline



0.5-2 minutes:

- First Alert from Seismic Alarms

1-5 minutes:

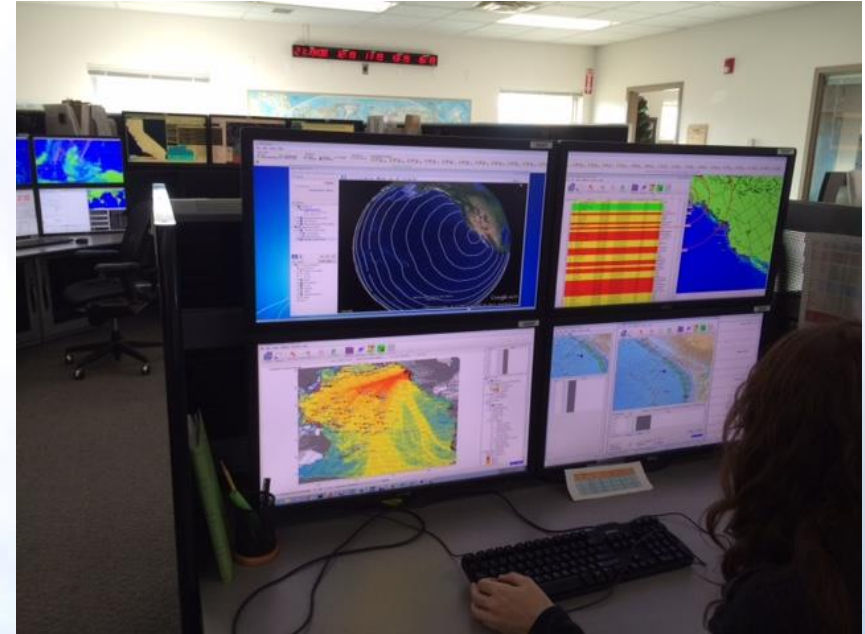
- Initial seismic processing complete and warning issued

20-90 minutes:

- First observation of tsunami on sea level gage

30-100 minutes:

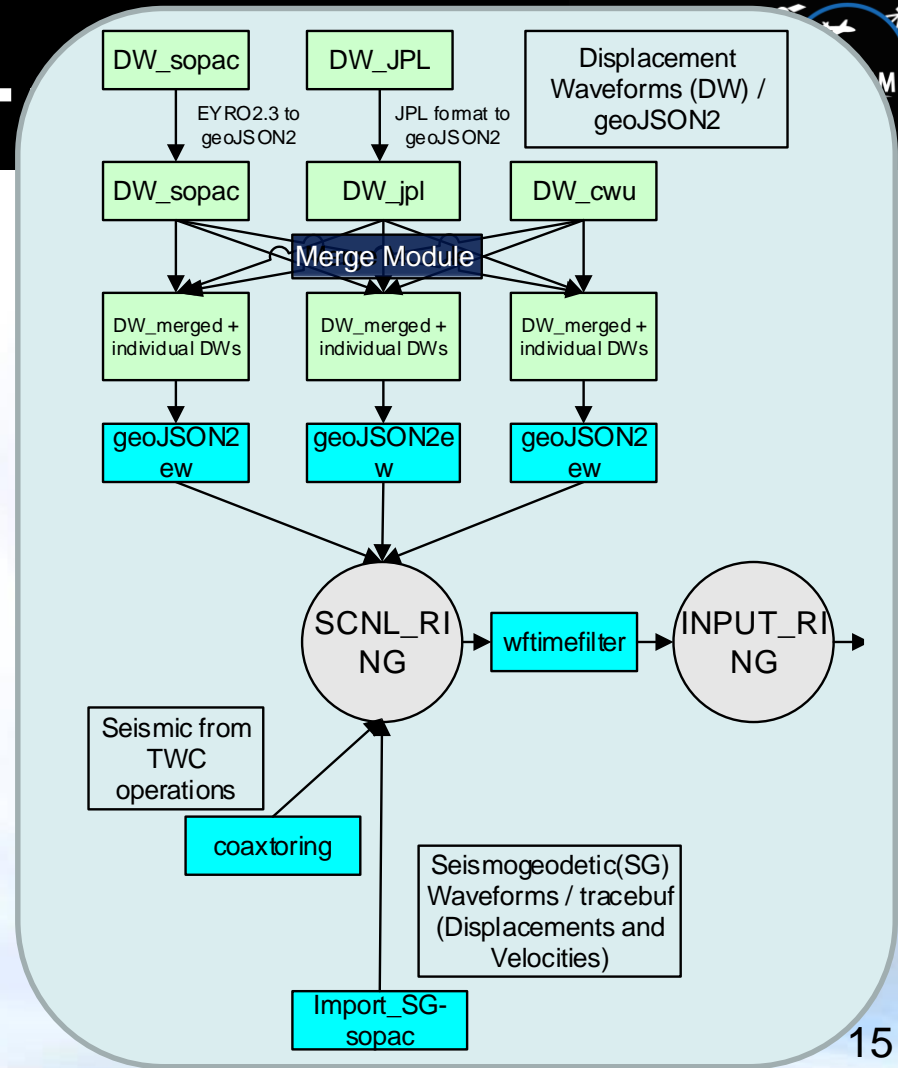
- Forecast based on models with assimilated sea level





# Bringing GNSS Data..

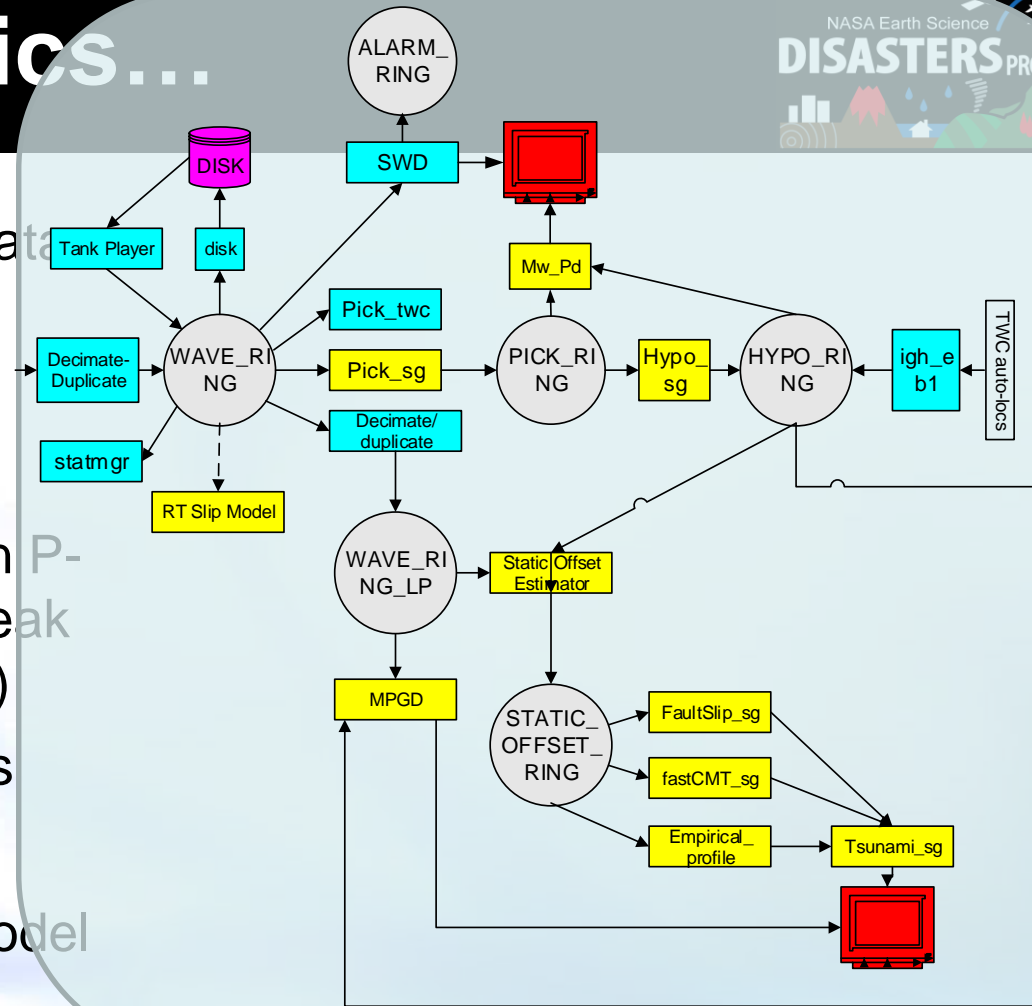
- Three GNSS Data Sources
- Redundant Merged Streams
- Standard Message Passing
- Seismogeodetic Data
- Earthworm Compatibility
- Delivered to both PTWC and NTWC



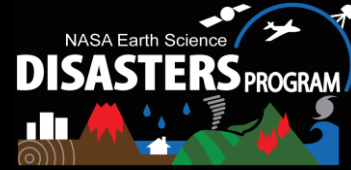
# Bringing Geodetics...

GNSS and Seismogeodetic Data  
Require Updated Algorithms

- P-wave picking
- Hypocenter estimation
- Magnitude scaling based on P-wave amplitude (Pd) and peak ground displacement (PGD)
- Finite-source CMT solutions
- Static fault slip models
- Tsunami source function model



# Status and Lessons Learned



Where are we now?

- Message passing infrastructure set up
- All groups are sending GNSS data
- Merging has been tested at all sites
- GNSS algorithms are ready but need to be wrapped

What have we learned?

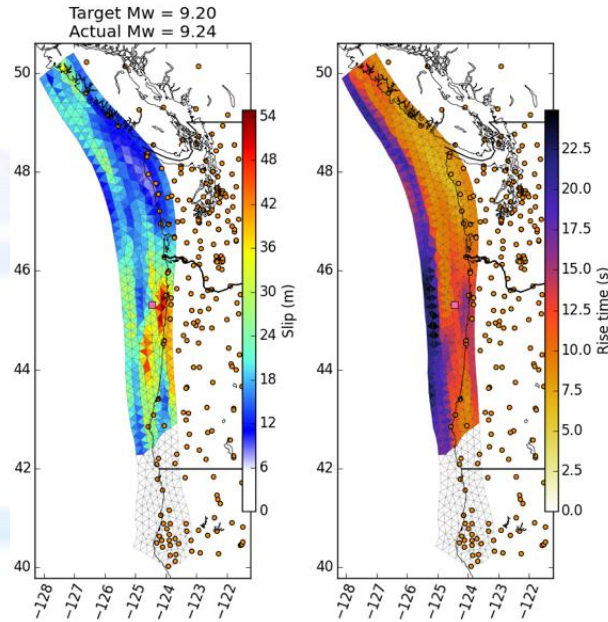
- The complexity of integration was underestimated
- Experiencing operations was crucial understanding needs
- The focused, hands-on process of communicating needs and capabilities culminated in the formation of a plan



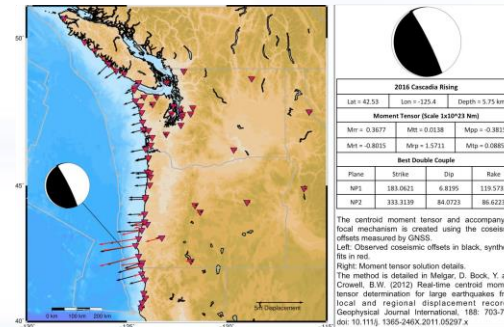
# Participation in Cascadia Rising



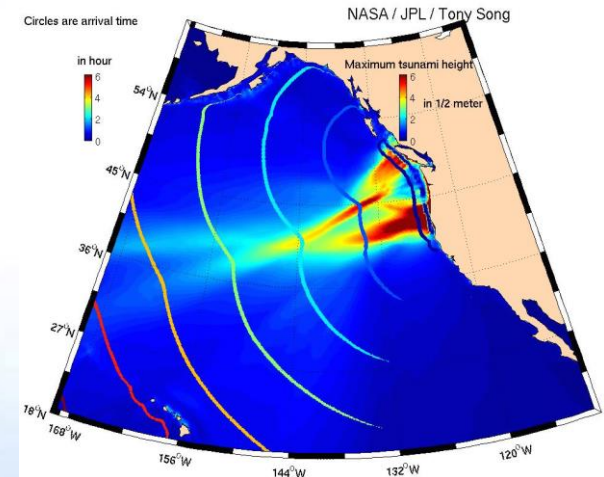
- NOAA and NASA cooperated in developing GNSS tsunami products for testing in the Cascadia Rising National Level Exercise (NLE)



*Fakequakes and GNSS Measurements*  
Melgar, UC Berkeley



Simulated Location and Magnitude Determination  
Bock, Scripps



Resulting Tsunami Source Function  
Song, NASA JPL

# Next Steps



- Create and leverage partnerships among researchers, developers and operational end users
- Enable collaborative evaluation and testing, co-development, integrated planning and program management
- Promote access and availability to critical low-latency data sources characterizing areas of highest risk
- Support unique and urgent opportunities to harvest mature research results, applications, and technologies
- Recognize that Research to Applications requires collaboration around shared objectives and takes considerable time and targeted resources

# BACKUP SLIDES

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